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Development route of the wind power industry in China

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ABSTRACT

Wind power is one of the world's major renewable energy sources, and its utilization provides an important contribution in helping solve the energy problems of many countries. After nearly 40 years of development, China's wind power industry now not only manufactures its own massive six MW turbines but also has the largest capacity in the world with a national output of 50 million MW h in 2010 and set to rise by eight times of that amount by 2020. This paper investigates this development route by analyzing relevant academic literature, statistics, laws and regulations, policies and research and industry reports. The main drivers of the development in the industry are identified as technologies, turbines, wind farm construction, pricing mechanism and government support systems, each of which is also divided into different stages with distinctive features. A systematic review of these aspects provides academics and practitioners with a better understanding of the history of the wind power industry in China and reasons for its rapid development with a view to enhancing progress in wind power development both in China and the world generally.

Contents

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1. Introduction

The development and utilization of renewable energy provides an important means of addressing the current issues of energy structure, climate change and government support in China [1] and helping to solve its current energy and environment problems, and a goal has been set for non-fossil fuels to account for at least 10% of primary energy consumption by 2020 [2]. Wind energy is one of the most promising renewable energy sources due to its availability and low cost and due to the fact that it is more efficient and advanced in technology [3]. Considering China's abundant inland and oceanic wind resources, it is clear that wind power will play a critical role in sustainable development and in the optimization of the structure of the energy industry in future [4].

Starting in the 1970s, China's wind power industry now provides a capacity that ranks first in the world, with a national output of 50 million MW h in 2010 and set to rise by eight times that amount by 2020. How has this come about and what are the lessons learned from this rapid growth? This paper identifies the main drivers of development in the industry and an understanding of progress to date. To achieve this, the development of the wind power technologies, turbines, wind farm construction, pricing mechanism and government support systems is systematically reviewed. This review provides academics and practitioners with a better understanding of the history of wind power industry in China and reasons for its rapid development with a view to enhancing progress in wind power development in China and in the world generally.

2. Overview of wind power development in China

China's main windy locations are the northern provinces (including autonomous regions) of Inner Mongolia, Xinjiang, Hebei, Jilin, Liaoning, Heilongjiang, Shandong, Jiangsu, Fujian and Guangdong [5]. Its long coastline also provides an abundant source of wind energy with, according to the 2007–2009 National Wind Energy Resource Survey, a total amount of exploitable wind energy on and offshore in the order of 1000–1500 gigawatts (GW) [6].

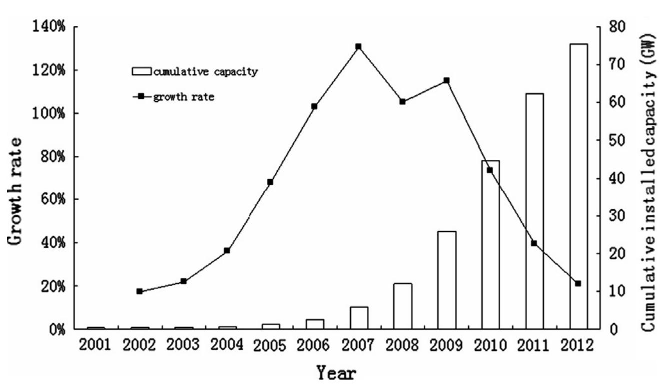


Fig. 1. Installed wind power capacity 2001 to 2012.
Source: [10].

Before 1996, China's wind power industry was in a pilot phase, with the majority of the country's wind power projects being supported by bilateral assistance programs and with most wind turbines made by foreign manufacturing companies [7]. Since then, the government launched a series of policies and national plans to support the introduction of wind power technology and large-scale development of the industry. These include the Wind Plan, National Research Programs (what is called the '863' Project), as well as bond-financed and concession wind power projects. Fig. 1 shows the year on year growth from 2001, with the rate of increase peaking in 2007, until, by 2012, new and grid-connected installed capacity was 15.9 and 61 GW respectively [8] – making both new and total installed wind power capacity ranked first in the world [9].

Today, China continues to strongly support the development of the wind power industry as evidenced by The National Energy Administration's 12th Five-Year Wind Power Development Plan's aim for substantial increases in capacity and proportion of national electricity generation leading up to 2020 (Table 1).

3. Development framework of the industry

The wind power industry in China comprises five major systems of wind power technology, turbines, wind farm construction, pricing mechanism and government support systems as illustrated in Fig. 2. The following sections provide an individual analysis of each of these five systems.

3.1. Technology

The development and manufacture of wind turbines in China started in the 1970s. From 1985 to 1995, a number of small pilot projects were constructed with the aid of loans from the Danish, German and Spanish governments. Since 1996, the wind power industry developed rapidly due to government support in the form of policies and national research projects so that, by 2000, Research and Development (R&D) was aiming at megawatt (MW)-level wind power equipment [12], with the first 1 MW turbine coming into operation in 2005 and progressing to 6 MW by 2011 (Table 2).

During the period of the 9th Five Year Plan (1996–2000), the focus was on developing 600 kW three-bladed, stall, and two-speed wind power generators. The overall assembly technologies were mastered during this time as well as the design and manufacture of key components such as blades, electrical controls, generators and gearboxes. Progress subsequently accelerated, with the 10th Five Year Plan (2001–2005) and National "863" Program

Table 1
Key Indicators of the 12th Five Year Plan for the development of wind power.
Source: [11].

Indicator category	Key indicators	Year		
		2010	2015	2020
Installed capacity	Land-based wind power (MW)	31,180	99,000	170,000
	Offshore wind power (MW)	132	5000	30,000
	Total (MW)	31,310	104,000	200,000
Electricity generating capacity	Total electricity generating capacity (10^9 kW h)	50	190	390
	Ratio of wind power in the total electricity generating capacity (%)	1.2	3	5

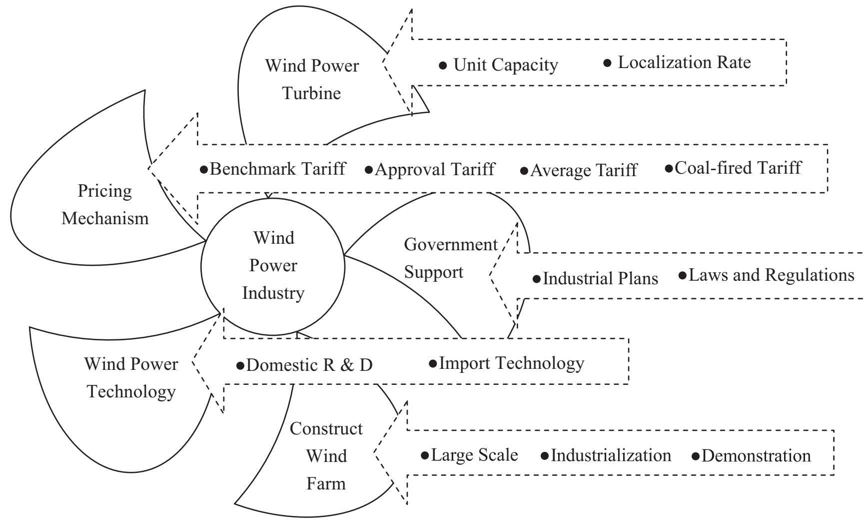


Fig. 2. Framework for the development of the industry.

Table 2
Milestones in wind power technology development.
Source: [13].

Year	Milestones/significant events
1975	Tsinghua University and the Institute of Grassland in Inner Mongolia collaborating with local animal husbandry and machine production enterprises trailed intensive micro-wind turbines with a capacity of 50 W and 100 W in Inner Mongolia.
1979	Independent research and development of experimental units and network operations started.
1986	Three 55 kW variable pitch wind turbines introduced from the Danish company *Vesta*, and established a small wind farm in Rongcheng of Shandong.
1991	Stall asynchronous wind turbine with unit capacity of 250 kW (the largest unit capacity available at the time) purchased from Germany.
1997	“The Wind Plan” issued and grid-connected wind turbines beginning to develop from research to market. Wind turbines, with the unit capacity of 200 kW, developed independently by China passed government appraisal.
1999	Xinjiang Gold Wind Technology Co. Ltd. and Zhejiang Arrival of Wind Power Engineering Co. Ltd. independently developed a 600 kW stall-type wind turbine.
2001	The development of MW-class of the double-fed wind generators and stall wind turbine listed in the National High Technology Research and Development Program by the Ministry of Science and Technology.
2005	Xinjiang Gold Wind Technology Co. Ltd. trailed the first MW class wind turbines in China. Shenyang University of Technology independently developed 1 MW double-fed wind turbines.
2008	1.5 MW wind turbines with direct drive permanent magnet variable speed and constant frequency produced with independent intellectual property rights.
2009	Xinjiang Gold Wind Technology Co. Ltd. developed and trailed 2.5 MW and 3 MW wind turbines in wind farms. Huarui Wind Power Technology Co. Ltd. developed a 3 MW offshore wind turbine that was connected with the grid in the East China Sea Bridge wind farm. 3 MW wind turbine developed by Shenyang University of Technology put into production.
2010	Development of wind turbines with stand-alone power above 5 MW.
2011	First 6 MW wind turbine developed independently by China officially put into operation.

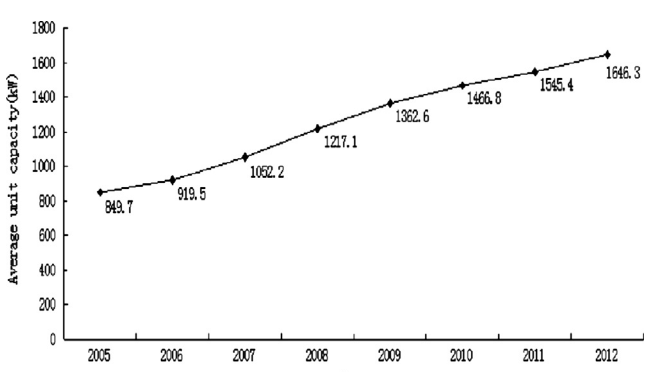


Fig. 3. Average unit capacity trend of newly installed wind turbines in China.
Source: [10].

supporting Chinese companies towards developing a MW-class wind turbine and associated key components. This resulted in the tracking of the world's mainstream advanced technology models and the Ministry of Science and Technology's initiation and completion of a research program for the development and mass production of a 750 kW stall wind turbine. The 11th Five Year Plan (2006–2010) extended this theme in the form of a national research program for the development and manufacture of increasingly powerful MW wind turbines.

At present, the main state of development of China's wind power manufacture and technology comprises: (1) MW-class turbines, (2) variable speed, variable pitch and constant frequency, (3) resistance to low temperatures, sand and salt spray, (4) fed induction power generation, and (5) high speed direct drive turbines [14].

With national policies encouraging the local production of wind power equipment, the level of wind power equipment manufactures has greatly improved. There is now a capability for the manufacture of key components such as gearboxes, blades and motors. Foreign investors have also begun to purchase many of these components [15].

3.2. Turbines

As is apparent from the previous section, the wind turbine is an important component in the development of wind power technology and an essential part of the wind farm. Generally, the cost

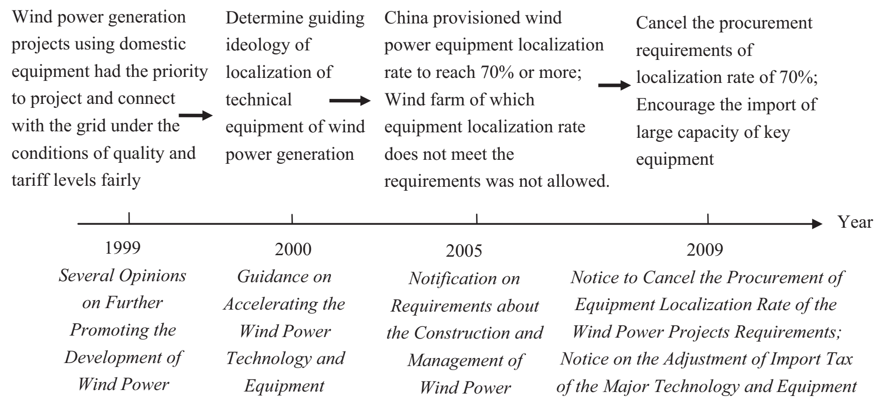


Fig. 4. Launch of policies encouraging local manufacture of wind power equipment in China.

Table 3
The three stages of development of wind farm construction.

Stage of development	Year	Milestones/significant events
Demonstration	1986–1990	4 wind farms built with 32 wind turbines installed. Total installed capacity 4.2 MW by the end of 1990.
	1990–1995	5 wind farms built with 131 wind turbines installed. Total installed capacity 33 MW by the end of 1995.
Industrialization	1996–2003	40 wind farms built with 1042 wind turbines installed. Total installed capacity 567 MW by the end of 2003.
Large-scale	Since 2003	More than 60 wind farms built with the total installed capacity of 1260 MW by the end of 2005. According to the wind resource planning, China mainly built 100 MW onshore wind farms. 1 GW and 10 GW wind farms planned to be built. At the same time, offshore wind farms under construction.

of wind power turbines accounts for 70–75% of the static investment involved [16]. Also, the turbine's capacity is an important indicator of the level of development of the industry. The following sections describe the development of wind power turbines in China in terms of their average unit capacity and increase in localization of their manufacture.

3.2.1. *Average unit capacity of newly installed wind turbines*

From 1992 to 1996, the main capacity of wind turbines in China was 200–300 kW. This increased to 600 kW over the period from 1997 to 2002. Since then, wind turbines have been mainly of MW-class, with the capacity of offshore wind turbines reaching 3–5 MW [9]. As Fig. 3 illustrates, the average unit capacities of newly installed wind turbines in China have grown steadily since 2005. By 2009, 1.5 MW wind turbine as a major product reached a 67% share of the Chinese market [17]. At present, the 3 MW offshore doubly fed wind turbine has been used in small batch applications, while the 6 MW turbine is now in mass production [18]. Because of rapid improvements in manufacturing technology, there is now an increasingly large capacity and diversified manufacture of wind turbine production in China.

3.2.2. *Localization rate of wind turbines*

Foreign turbine units were introduced in the early development stage of China's wind power industry, with a major measure being government support of the import of wind power equipment through a series of tax incentives and other policies. As illustrated in Fig. 4, the government later launched a series of financial support policies and provided research and development funds to encourage improvement in local production rates. From 2003, the government accelerated the local production of wind power equipment through a wind power project concession

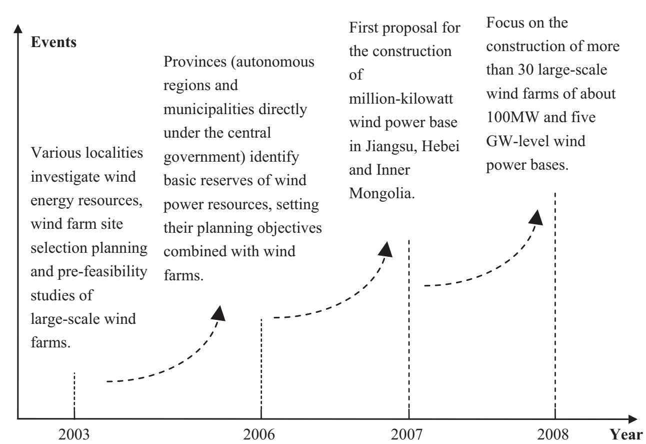


Fig. 5. Milestones in the development of China's wind farm construction since 2003.

scheme with specific requirements concerning localization rates [19].

Since 2009, localization rates of wind power projects have been abolished in order to establish an open and competitive wind power market. The owners of wind power projects can now purchase equipment independently through open bidding in accordance with the requirements of the Bidding Law [20]. The wind power equipment supply market has therefore been effectively opened up by encouraging fair competition between foreign and local manufacturers, a move that many believe to be conducive to the healthy development of China's wind power industry as a whole.

3.3. Wind farm construction

Generally, the development of wind farm construction in China can be divided into three stages: the initial demonstration stage, the industrialization stage and the large-scale development stage as shown in Table 3.

3.3.1. Demonstration stage (1986–1995)

The development of grid-connected wind power in China started in 1986. In May 1986, the Malan Bay wind farm, the first such farm in China, was built in the Rongcheng City of Shandong. The Shandong Provincial Government and the Ministry of Aviation Industry jointly allocated foreign exchange to introduce and install Vestas V15-55/11 wind turbines. Since then, wind turbines have been introduced to construct grid-connected wind farms by means of government funding, foreign grants or concessional loans.

Overall, the construction of wind power farms in this phase is characterized by the use of foreign grants and loans to build small demonstration farms, with the government providing financial support for wind farm investment and wind turbine research and development.

3.3.2. Industrialization stage (1996–2003)

During 1996, the government began to promote a local wind power industry through policies such as Wind Plan and Double-plus Project, devised to localize the manufacture of wind power equipment. This played an important role in nurturing the emerging wind power industry and enabling the gradual entry of wind farms into their commercialization period. However, high construction costs and on-grid prices, as well as the technological barriers involved in moving to the large-scale production methods, restricted the development of the industry to less than 100 MW per year newly installed capacity.

3.3.3. Large-scale development stage (2003–present)

Fig. 5 shows the milestones in the development of China's wind farm construction since 2003, when The National Development and Reform Commission (NDRC) called on all localities to carry out a thorough investigation of their wind resources, site selection of wind farms, and the pre-feasibility study of the construction of large wind farms. That work was completed in 2006, at which point all provinces (autonomous regions and municipalities) fully understood their basic reserves of wind power resources and were able to set targets for wind farm planning and site selection.

In August 2007, the Renewable Energy and Long-term Development Plan was issued by the NDRC, proposing the construction of 1 GW wind power bases in Jiangsu, Hebei, and Inner Mongolia [21]. The following year, the Commission issued its Renewable Energy Development for 11th Five-Year Plan, emphasizing the construction of 30 large (more than 100 MW) wind farms and 5 GW-level wind power bases in Hebei, Inner Mongolia, Gansu, and Jilin due to the rich wind power resources there, and the preparation and construction of 10 GW wind power bases in the coastal areas of Jiangsu and Shanghai [22].

At that time, and in order to promote the large-scale development of the wind power industry, the draft of Renewable Energy Development in the 12th Five-Year Plan proposed the construction of six 10 GW wind power bases and several GW wind power bases in Hebei, east Inner Mongolia, west Inner Mongolia, Jilin, Gansu and Xinjiang, with a total capacity of 65 GW [23]. Additionally, large to medium wind farms were to be constructed in Shanxi, Liaoning, Heilongjiang, and Ningxia; small and medium-sized wind power projects in Henan, Jiangxi, Hunan, Hubei, Anhui, Yunnan, Sichuan, Guizhou and other inland provinces. The coastal areas of Jiangsu, Shandong, Hebei, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi and Hainan were also to focus on the development and construction of offshore wind farms, aiming to achieve a 5 GW capacity of offshore wind power and 5 GW capacity under construction by the year 2015 [23].

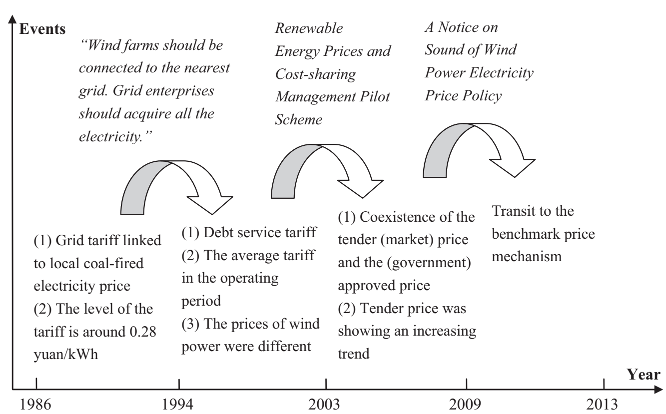


Fig. 6. Evolution of the wind power pricing mechanism.

3.4. Pricing mechanism

During the last three decades, the wind power pricing mechanism in China has changed due to the different development stages and national incentive policies involved (Fig. 6). This evolutionary process can be divided into the four stages as follows.

Table 4
The four types of wind energy resource area and their benchmark price.
Source: [27]

Resource area	Benchmark price (yuan/kWh)	Areas
Class I resource area	0.51	Inner Mongolia Autonomous Region except in Chifeng City, Tongliao City, Hing'an Hulunbeier City; Urumqi, Ili Kazak Autonomous Prefecture, Changji Hui Autonomous Prefecture, Karamay and Shihezi City.
Class II resource area	0.54	Zhangjiakou City, Chengde City in Hebei Province, Chifeng City, Tongliao City, Hing'an Hulunbeir in Inner Mongolia Autonomous Region; Zhangye City, Jiayuguan City and Jiuquan City in Gansu Province.
Class III resource area	0.58	Baicheng City, Songyuan City in Jilin Province; Jixi City, Shuangyashan, Qitaihe City, Suihua City, Yichun City and Daxinganling region in Heilongjiang Province; Gansu Province except Zhangye City, Jiayuguan City, Jiuquan City; Xinjiang Uygur Autonomous Region except Urumqi, Yili Kazak Autonomous Prefecture, Changji Hui Autonomous Prefecture, Karamay, Shihezi City and the Ningxia Hui Autonomous Region.
Class IV resource area	0.61	Other than Class I, II, III resource area

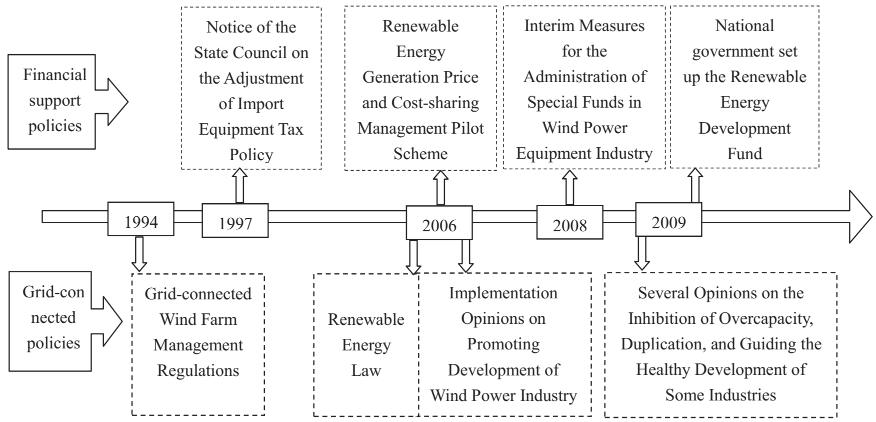


Fig. 7. Laws and regulations related to wind power development.

3.4.1. Reference to coal-fired electricity phase (1986–1993)

The tariff of this stage mainly depended on the construction of wind farms. As wind power equipment at this time was obtained mainly through government funding and foreign grants, the construction of the farms was mainly for research and investigation and not yet for commercial operation. Wind power price was therefore set by government policy, which was based on the local coal price. The wind power in-grid tariff was determined by an agreement between the wind power plants and power grid companies subject to the approval of the relevant government departments. The price level at this stage was approximately 0.28 yuan/kW h [24].

3.4.2. Average tariffs determined by debt service and operating cost (1994–2002)

China's electric power system reforms in 1994 dictated that all wind power generated electricity be fed into the power grid and purchased by the grid companies, with the tariff being a function of the power generation costs plus debt service and a reasonable profit. In the event of the tariff being higher than the average grid price, the difference was borne by the grid companies [24].

Due to the different distribution of wind resources and degrees of wind resource utilization support levels by local governments for the industry, the price of wind power electricity was not unified during this period and ranged from a minimum of 0.3 yuan/kW h to a maximum of 1.2 yuan/kW h depending on the location involved [25].

3.4.3. Government guidance price and approval price phase (2003–2009)

In this stage, the price of wind power was determined by either government guidance price or approval price, with the government guidance price being the bid price obtained through the open tender of wind power concession projects [26] and approval price being the price determined by government.

In 2003, the NDRC initiated open bidding for the national wind electricity concession projects, which began to introduce a market competition mechanism into wind farm development. Then the wind electricity tariff was determined by tendering [24]. In 2006, the NDRC issued its Renewable Energy Prices and Cost-sharing Management Pilot Scheme, in which the feed-in tariff for wind power projects followed the government-guided price, which was determined by the bidding process [26]. Most of the provinces not using open tendering continued to use the approved tariff pricing method, with the tariff generally comprising the feed-in tariff of local desulfurized coal-fired power plants plus a grid subsidy of no more than 0.25 yuan/kW h [24].

3.4.4. Four categories of the benchmark tariff (2009–present)

In August 2009, the NDRC issued A Notice on Wind Power Electricity Price Policy, implementing a fixed-price policy for different wind power locations. This divided wind power farms into four wind resource areas based on wind-energy resource distribution and construction conditions. The corresponding wind power benchmark tariff is shown in Table 4 [27]. The on-grid tariff of new projects is determined by their corresponding wind resource areas. This fixed-tariff policy unifies the standard of wind electricity tariffs throughout China, not only corresponding with the distribution of wind resources, but also providing a reliable reference for wind generated electricity investors and facilitating the large-scale development of China's industrial wind power.

3.5. Government support

The development of the industry's government support system can be appreciated in terms of industry planning and government regulations as follows.

3.5.1. Industry planning

The Renewable Energy and Long-term Development Plan released in 2007 and Renewable Energy 11th Five-Year Plan in 2008 promulgated the country's advance in wind power technology, increase in localization of equipment manufacture and competitiveness of the industry through large-scale wind power development and construction [21,22].

After experiencing a rapid growth in wind power capacity, the government turned its attention to the effectiveness of wind power development. In 2011, the National Economic and Social Development 12th Five-Year Plan of China strengthened grid construction, supporting wind power projects and effectively developing the wind power industry. This involves the coordination of:

- wind resource planning and grid development planning,
- construction of the power grid and wind power farms to avoid problems such as being unable to connect wind farms to the grid, and
- the development of energy of wind, water and fire resources to increase peak load capacity [28].

3.5.2. Laws and regulations

Over the years, China has established a legal and policy system to encourage and promote the healthy development of the wind power industry as shown in Fig. 7. In 1995, the Electricity Law was

launched and for the first time the government encouraged and supported the use of renewable energy. Next, the Energy Conservation Law was enacted in 1997, by which local governments were required to provide funds for energy saving by the rational use of energy and the development of renewable energy sources as appropriate for the local situation [29]. Later, a special Renewable Energy Law was enacted in 2005 (revised December 2009), specifically for the development and utilization of renewable energy. This introduced detailed implementation rules, including wind power financial support and wind power connect-grid policies [30].

4. Conclusion

The wind power industry in China has undergone tremendous changes in terms of technology, turbines, farm construction, pricing mechanisms and government support systems. Starting with the manufacture of small equipment, followed by importation from foreign countries, the technology gradually increased with independent research and development to the current manufacture of large-scale wind power equipment seen today. The average unit capacity of wind power turbines in recent years has grown dramatically from early government support in importing wind power turbines, supporting the development of domestic wind power equipment through concession wind power projects, to gradually removing localization requirements on wind power turbine manufacture to establish an open market. The construction of wind power farms themselves experienced three phases of demonstration, industrialization and large-scale development. Based on the distribution of China's natural inland and oceanic wind resources, a national system has been created of wind farms of different levels of capacities selectively constructed throughout the country.

The development of the wind power pricing mechanism follows the development stages of the wind power industry itself, varying greatly in the process, and divides into four stages from reference to coal-fired electricity price (1986–1993), average tariffs of debt service and operating (1994–2002), government guidance and approval (2003–2009) to the current four categories of benchmark tariff. Finally, the development of the wind power industry's government support system was heavily dependent on industrial planning and associated regulations. Industrial planning focused on increasing the use of wind energy sources and encouraging the development of the wind power industry while, at the same time, laws and regulations gave legal protection and support for the development and utilization of renewable energy, providing direction for the development of wind and other renewable energy sources.

After a long period of exploration and development, China's wind power industry is now the world's leader. Its development path has been a salutatory aspect in this accomplishment, and provides valuable experience for the future development of the wind power energy and utilization of other renewable energies in both China and the world in general.

Acknowledgments

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